1.3 EFFECTS OF 1998 ENSO EVENT ON OUTGOING CLEAR-SKY LONGWAVE RADIATION OVER TROPICAL OCEANS: INITIAL RESULTS FROM CERES

Takmeng Wong*, Martial P. Haeffelin, Stephanie A. Weckmann, and David F. Young
NASA/LaRC, Hampton, VA

1. INTRODUCTION

The Clouds and the Earth's Radiant Energy System (CERES) is a new space borne measurement program for monitoring the radiation environment of the Earth-atmosphere system (Wielicki et al., 1996). The first CERES instrument was launched into space on board the Tropical Rainfall Measuring Mission (TRMM) satellite during the midst of the 1997/1998 El Niño/Southern Oscillation (ENSO) episode. This study examines the effects of the 1998 ENSO event on the outgoing top-of-the-atmosphere (TOA) clear-sky longwave (CLW) radiation field over the tropical oceans using a combination of CERES and Earth Radiation Budget Experiment (ERBE; Barkstrom, 1984) observations and radiative transfer model simulations. Section 2 will give a brief overview of the datasets used in this study. Analysis of the CLW will be discussed in section 3. Section 4 will show the results of the comparisons between observation and theory. Section 5 will discuss the effects of the ENSO SST and PWC anomalies on the TOA CLW field. A final summary and conclusion will be given in section 6.

2. DATA AND MODEL DESCRIPTION

Two CLW data sets are used in this study. They come from the CERES/TRMM ES-4G (January to July 1998) and the ERBE/ERBS S-4G (January 1985 to December 1989) data products. Both data sets contain regional 2.5 degree gridded mean of monthly-mean TOA emitted longwave and reflected shortwave radiation for total-sky and clear-sky conditions. For this study, only regional monthly-mean clear-sky longwave radiation data over the tropical oceanic regions between 30 N and 30 S latitude are extracted for analyses. The radiative transfer model used in this study is the Fu-Liou plane-parallel, delta-four-stream model (Fu and Liou, 1993). The clear-sky longwave part of this model uses a correlated-k treatment of gaseous absorption and emission for H_2O, CO_2, O_3, O_2, CH_4, and N_2O. Continuum absorption of H_2O is included. Twelve spectral intervals are used in the longwave. The model uses inputs from the NOAA Reynolds sea surface temperature (SST) dataset and the temperature and moisture data from NOAA/NCEP. In additions, McClatchey tropical atmospheric moisture information is also used to uniformly fill in the missing NOAA moisture profile above the 300-mb surface.

* Corresponding author address: Takmeng Wong, NASA/LaRC, MS 420, Hampton, VA 23681-2199; e-mail: takmeng.wong@larc.nasa.gov

3. OBSERVATIONAL ANALYSIS

Figure 1a shows the time series of the tropical mean oceanic CLW radiation (defined as the average CLW value for all oceanic regions between 20 N and 20 S latitude) for the first seven months of 1998 CERES data and their corresponding climatological average and extremes during the ERBE period. Figure 1b gives the corresponding time series of the NOAA/CDC multivariate ENSO index value for the same period. Two features are evident from inspection of this figure. First, an ENSO-like behavior in the tropical mean CLW is found in the CERES dataset. Specifically, the temporal CLW fluctuation in Fig. 1a is well correlated with the time variation of the NOAA ENSO index in Fig. 1b. This provides the first direct observational link between the behavior of the CLW energy field and the evolution of 1998 ENSO event. Second, the CERES tropical mean CLW is much larger than the ERBE climatology during most of the 1998 ENSO event. These differences, however, diminished completely by the end of the ENSO event in July 1998.

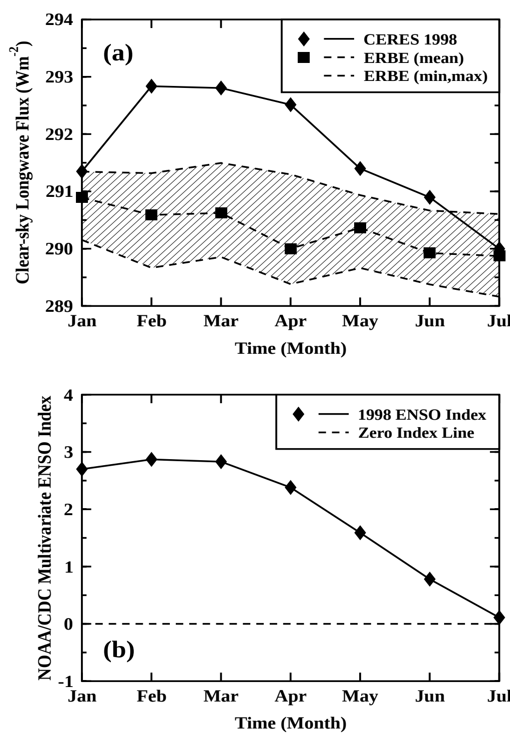

Fig. 1. Time series of (a) CERES clear-sky longwave tropical mean and the corresponding ERBE climatological mean and extremes and (b) NOAA ENSO index during the first seven months of 1998.

The largest CLW differences between the CERES and the ERBE data for 1998 is about 2.6 Wm^{-2}. This is much larger than the temporal sampling noise (about 1 Wm^{-2}) associated with the orbital differences between the TRMM and the ERBS spacecrafts and is indicative of the net warming effect caused by the 1998 ENSO event over the tropical oceans.

Spatial analyses of the CLW and the CLW anomaly field for February 1998, corresponding to the peak of the 1998 ENSO event, are also performed to further highlight the regional effects of this ENSO event. The statistical summary of these analyses for oceanic regions between 30 N and 30 S latitude is shown in Table 1. Figure 2 shows the corresponding observed zonal average profile (solid line) for February 1998. In general, three large scale zonal CLW features are noticeable in Fig. 2a. They are (1) a zone of maximum CLW radiation centered near 10 to 15 N, (2) a zone of minimum energy at the equatorial region, and (3) a zone of secondary maximum radiation centered near 15 S. The mean value and standard deviation of the observed February 1998 CLW radiation over the tropical oceans are 291.5 and 7.4 Wm^{-2}, respectively. The zonal mean CLW anomaly field (given in Fig. 2b) shows a similar pattern with maximum positive anomaly centered near 15 N, an equatorial minimum anomaly centered just south of the equator, and a secondary maximum positive anomaly at 15 S. This zonal feature indicates that the February 1998 ENSO event had a net cooling effect, relative to ERBE climatology, over the equatorial regions and a relative net warming influence away from the equator. The mean and standard deviation of the February 1998 CLW anomaly field over the tropical oceans are 2.2 and 4.7 Wm^{-2}, respectively.

TABLE 1**.** Statistical summary (Wm^{-2}) for February 1998.

	CLW		CLW anomaly	
	Mean	Sigma	Mean	Sigma
CERES	291.5	7.4	2.2	4.7
Model	287.5	7.0	2.3	5.2

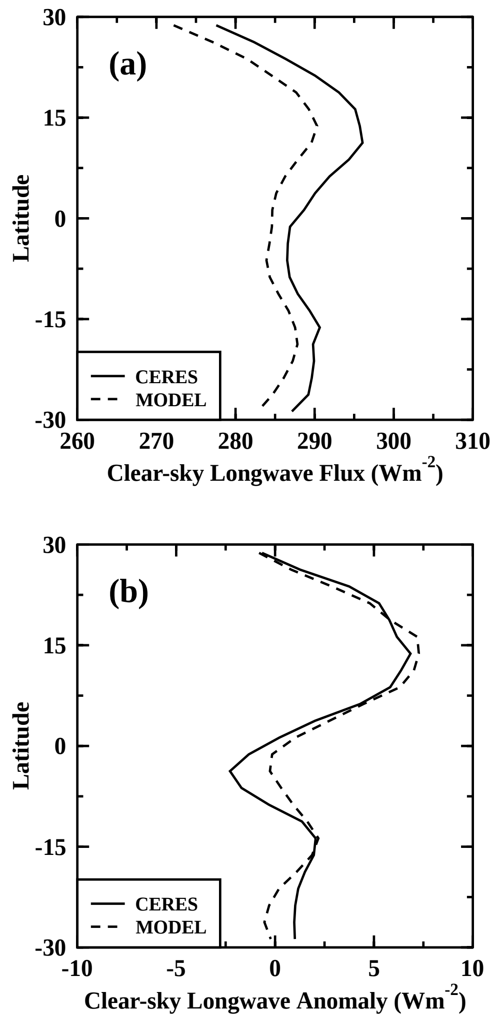

Fig. 2. Observed (solid) and simulated (dashed) zonal mean profile of (a) clear-sky longwave and (b) clear-sky longwave anomaly field for February 1998.

4. COMPARISON WITH MODEL SIMULATIONS

In order to explore the theoretical consistency of the CLW observations with the underlying atmospheric and surface conditions associated with the 1998 ENSO event, clear-sky radiative transfer simulations are carried out. Regional analyses of the simulated CLW and CLW anomaly field for February 1998 are performed to facilitate comparison with observations. The statistical summary for these simulations is given in Table 1. Figure 2 (dashed line) shows the corresponding zonal average profile for the February 1998 simulations. Despite a small global bias of -4 Wm^{-2} in the simulation, the model reproduced all the major features of the observed CLW energy fields. The low bias associated with the simulated data shows up clearly in Fig. 2a and is due in part to the high water content of the McClatchey tropical profile used in the simulation. The high upper level atmospheric water content is known to reduce outgoing longwave radiation. The standard deviation of the simulated data is 7 Wm^{-2} and compares well to the 7.4 Wm^{-2} from the observations. The correlation coefficient between the observed and simulated regional CLW is 0.8.

The model also performed very well in simulating the observed CLW anomaly field during February 1998. This is evident in Fig. 2b. For example, the locations of the observed equatorial minimum anomaly and the net warming effects away from the equator are well simulated by the model. The mean and the standard deviation of the simulated anomaly are 2.3 and 5.2 Wm^{-2}, respectively. These values compare very favorably with observations. The correlation coefficient between the observed and simulated regional CLW anomaly field is 0.73. These good spatial agreements between observation and simulation indicate that the spatial pattern of the February 1998 CLW and CLW anomaly fields are consistent with the underlying atmospheric and surface spatial features associated with the February 1998 ENSO event.

Radiative transfer simulations for the other months of the 1998 ENSO event are also performed to examine the temporal consistency between CLW observations and underlying changes in atmospheric and surface conditions. The results of the comparison between observations (gridded) and simulations (shaded) are shown in Fig. 3 in the form of a bar chart representing the time series of the monthly tendency of the oceanic tropical mean CLW during the first seven months of 1998. The monthly tendency is defined as the change in oceanic tropical mean CLW between two consecutive months. The agreement between observations and simulations is apparent in this figure. Specifically, the CLW tendency is positive/negative for both observation and simulation during the first two months/last four months of the series, respectively.

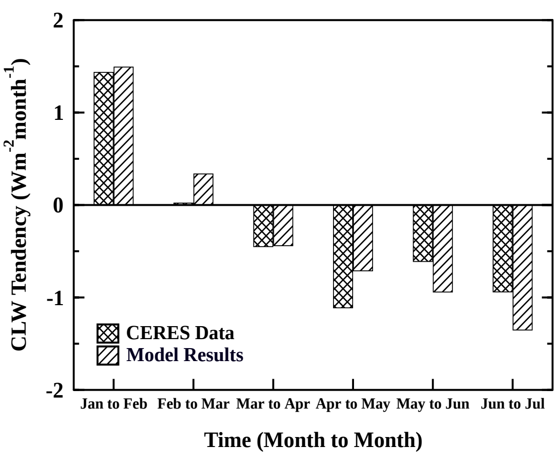

Fig. 3. Time series of monthly tendency of observed (gridded pattern) and simulated (shaded pattern) clear-sky longwave tropical mean value during the first seven months of 1998.

The excellent temporal and spatial agreements between observations and simulations shown in this section indicate that the CERES CLW observations are theoretically consistent with the changing surface and atmospheric conditions associated with the 1998 ENSO event. Therefore, the observed CERES CLW features are the direct responses of the longwave radiation to the ENSO atmospheric and surface anomalies.

5. EFFECTS OF ENSO SST AND PWC ANOMALIES

Using the January 1998 ENSO episode as a natural test-bed for understanding physical processes associated with this ENSO event, data analyses are carried out to examine the effects of ENSO SST and atmospheric column precipitable water content (PWC) anomaly on outgoing CLW anomaly over the tropical oceans. Specifically, we want to express the observed ENSO CLW anomaly in terms of fundamental ENSO changes in SST and PWC. An ENSO event is normally marked by a large-scale east-west displacement of SST over the tropical Pacific. This east-west migration of SST, in turn, sets up a chain reaction in the atmosphere which ultimately results in changes in the hydrological cycle over the entire tropics. Since outgoing CLW radiation over the ocean is strongly coupled to both the SST and the PWC field, changes in these two variables during an ENSO event can directly be translated into changes in outgoing TOA CLW radiation. While the change in CLW, in theory, is positively related to changes in SST in a dry atmosphere, it is negatively associated with changes in PWC. In addition to these direct forcings, SST can also indirectly affect CLW by modifying the PWC field. This indirect forcing, however, is not explored in this study. Instead, we will only concentrate on examining the effects of the direct forcings.

The results of our observational analyses are given in Fig. 4 in the form of a scatter diagram. In contrast to the theory, the scatter diagram of January 1998 SST anomaly versus CLW anomaly in Fig. 4a has a negative slope, suggesting an increase in SST can lead to a decrease in CLW. The significance of this relationship, however, is not very strong as indicated by the low value of correlation coefficient (R value of 0.26). As seen in Fig. 4a, the observed SST anomaly field for January 1998 is very poorly correlated with the CLW anomaly. The points in the figure are basically clustered at the center of the diagram. Therefore, we reject this negative relationship and conclude that there is very little correlation between the observed SST anomaly and CLW anomaly in the moist tropical atmosphere. Fig. 4b shows the effects of the January 1998 PWC anomaly on the CLW anomaly field. Unlike the SST results, the effect of PWC anomaly on TOA CLW field is consistent with theory. Specifically, a negative relationship is reduced from the data. The correlation coefficient between the two fields is 0.63. This is much higher than the R value noted early for the SST anomaly filed. As seen in Fig. 4b, the observed PWC anomaly field for January 1998 is well correlated with the CLW anomaly field and the points in the figure are nicely clustered around the regression line. The regression line has a negative slope of -0.568 and an offset of 1.515.

The lack of correlation between SST anomaly and CLW anomaly field and the observed negative relationship between PWC anomaly and changes in TOA CLW radiation field are consistent with the physics of the tropical atmosphere. In the moist tropical atmosphere, the longwave energy emitted from the surface is completely absorbed by water vapor in the atmosphere. This radiation is re-emitted back to the atmosphere. The level at which this re-emission occurs is depended on the column water vapor content. When the atmosphere is dry, longwave energy is able to escape from the lower troposphere to the TOA and the net effect is an increase in outgoing CLW radiation at TOA. As the moisture content of the atmosphere increases, the effective longwave emission level in the atmosphere moves upward, away from the surface and the net effect is a decrease in outgoing CLW. These observed features also highlight (1) the significant role of water vapor field in modulating the tropical TOA outgoing CLW radiation field and (2) the important effects of water vapor absorption of the tropical atmosphere in decoupling the TOA outgoing CLW energy field from their surface counterparts.

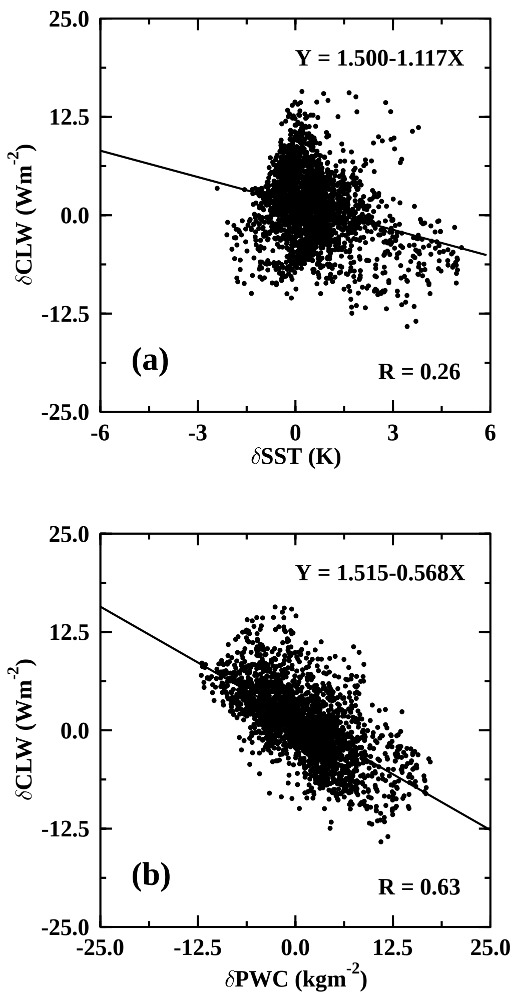

Fig. 4. Scatter diagram of (a) NOAA sea surface temperature (SST) anomaly field versus CERES clear-sky longwave (CLW) anomaly and (b) NOAA precipitable water content (PWC) anomaly versus CERES CLW anomaly field for January 1998.

6. SUMMARY AND CONCLUSION

This study examines the effects of the 1998 ENSO event on the outgoing TOA CLW radiation field over the tropical oceans using a combination of new CERES and historical ERBE observations and radiative transfer model simulations. Observational analyses of CLW are performed for the fist seven months of 1998. An ENSO-like feature is found in the time series of CLW field. The temporal CLW fluctuation is well correlated with the time variation of the NOAA ENSO index. This provides the first direct observational link between the behavior of the CLW energy field and the evolution of 1998 ENSO event. The CERES tropical mean CLW is also much larger than the ERBE climatology during most of the 1998 ENSO event and is indicative of the net warming effect caused by the 1998 ENSO event over the tropical oceans. These differences, however, diminished completely by the end of the ENSO event in July 1998. Comparison of the spatial and temporal features of the observed and simulated CLW distribution/anomaly are performed to study the effects of background meteorological anomalies during the 1998 ENSO event. It is found that (1) the simulated CLW and CLW anomaly fields for February 1998 are consistent with CERES observations and (2) the temporal evolution of the CLW field during 1998 is well captured by the model. These excellent spatial and temporal agreements between observations and simulations indicate the observed CERES CLW features are the direct responses of the CLW radiation field to the1998 atmospheric and surface ENSO anomalies. Using the January 1998 ENSO episode as a natural test-bed for understanding physical processes of the 1998 ENSO event, data analyses are carried out to examine the relationship between changes in SST and PWC fields and outgoing CLW anomaly. While the changes in the SST pattern are basically uncorrelated with changes in CLW field, negative correlation is found between PWC anomaly and the changes in TOA CLW radiation field. These observed features point to (1) the significant role of water vapor field in modulating the tropical TOA outgoing CLW radiation field and (2) the important effects of large water vapor absorption of the tropical atmosphere in decoupling the TOA outgoing CLW energy field from their surface counterparts.

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